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Histopathologic Evaluation of Conventional and Giromatic Methods of Canal Preparation on Pulp Stump and Periapical Tissues

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HISTOPATHOLOGIC EVALUATION OF CONVENTIONAL AND
GIROMATIC METHODS OF CANAL PREPARATION ON
PULP STUMP AND PERIAPICAL TISSUES

by

Gerald Daniel Gray

A Thesis Submitted to the Faculty of the Graduate School
of Loyola University in Partial Fulfillment of
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DEDICATION

To my wife and closest friend, Susan, whose love makes my life complete, and to my parents who have given me so much, for so long, especially their love.

VITA

The author, Gerald Daniel Gray, is the son of Lester Allan Gray and Loretta (Murphy) Gray. He was born February 26, 1947, in Evanston, Illinois.

His secondary education was obtained at Notre Dame High School, Niles, Illinois, where he graduated in June 1965.

In September, 1965, he entered the University of Arizona, where he completed two years of study. He completed an additional year of study at California State University at Long Beach and two additional years at the University of Southern California, where he graduated in June, 1970, with the degree of Bachelor of Science with a major in biology.

In September, 1970, he entered the Loyola University School of Dentistry, where he received the degree of Doctor of Dental Surgery in June, 1974. While attending dental school he was elected a member of Omicron Kappa Upsilon, Alpha Sigma Nu, and Blue Key. He was awarded a special achievement award from the American Academy of Periodontology in 1974.

In July, 1974, he began a residency in general dentistry at the veterans Administration Hospital, Portland, Oregon, and completed the residency in June, 1975.

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INTRODUCTION

For centuries, man has been faced with the perplexing problem of what to do with the diseased tooth. Historically, a great deal has been written about the dilemma and what, if anything, to do to treat the diseased organ (1,2,3).

Amputation of the diseased tooth was recommended by many, as it provided a "cure" when technical knowledge of proper treatment was almost universally nonexistent. Late in the eighteenth century and early in the nineteenth century dental pulps were extirpated and attempts to fill the root canals with gold foil were performed. Similarly, wooden pegs were driven into the root canals. By 1825 pharmacology had entered the battle. Pulpotomies and pulpectomies followed by the use of various drugs seemed to be the best method of treatment. In these attempts to save the tooth, oil of cloves, oil of cajoput, opium, alum, arsenic and others were used.

Around the turn of the twentieth century, Kells is credited with a technological advancement when he used roentgenograms to inspect the root canal system following treatment.

With the knowledge of the root canal system, aided by its visualization on the roentgenogram, there came a cry for the development of instruments that could facilitate an easy method of removing the diseased contents of a tooth. The empirical attempts of these pioneers who

faced this perplexing problem formed the basis for the field of endodontics. Endodontics has been defined as "that branch of dentistry concerned with the etiology, prevention, diagnosis, and treatment of diseases and injuries that affect the pulp and periapical tissues".(4)

Even today, in the age of advanced technology, the search for new and improved methods of endodontic treatment continues. Now, however, we have a vast knowledge both of the problem and the correct therapy. As stated by Weine, the objective of endodontic therapy is restoration of the treated tooth to its proper form and function in the masticatory apparatus, in a healthy state.(5) Although Luks gives perhaps too limited a view when he gives his overall objective in endodontic treatment as the complete removal of all tissue, vital or necrotic, it does indicate the importance he places on canal instrumentation.(6)

The Second International Conference on Endodontics listed its principles for endodontic treatment as:

- (1) an aseptic technique should be followed
- (2) instrumentation should be confined to the root canals
- (3) a canal should be entered by a fine, smooth canal instrument
- (4) the root canal should be enlarged no matter how wide initially
- (5) the canal should be flooded during instrumentation in order to lubricate the intracanal instrument, reduce the number of microorganisms, and inhibit the dentinal shavings from flinging to the instrument or packing in the canal (7)

Among his criteria for successful endodontic therapy, Stewart lists the necessity of establishing aseptic conditions, utilization of sterile instruments, and complete elimination of infected or inflamed tissues.(8)

Among the basic principles for successful endodontics as given by

Fink are 1. remove all decay and leaky fillings; 2. develop a sterile technique; 3. obtain direct access along straight lines with the root canals; 4. preserve the pulpal floor; 5. never instrument a dry canal; 6. instrument short of the radiographic apex by .5 to 1.0 mm; and 7. debride all canals thoroughly.(9)

At the Third International Conference on Endodontics, Frostell presented a study on the factors influencing the prognosis of endodontic therapy in which he emphasized the necessity for thorough cleansing and debridement of the root canals as well as instrumenting and obturating the canals to within 1.0 mm of the root apex.(10)

With the emphasis now placed upon the canal instrumentation, and less upon therapeutics, a new mechanical device has been introduced recently, with claims of being faster, safer and easier than conventional instruments. The effects of this new device, the giromatic, upon vital soft tissues has not as yet been studied.

The purpose of this study is to evaluate the effects of intracanal instrumentation at various distances from the apex on pulp stump and periapical tissue while using the conventional hand instrument system as compared to the giromatic system.

REVIEW OF THE LITERATURE

The battle against existing "endodontic diseases" had, until recently, been fought with intradental medicaments. During these decades of chemical warfare, there were some who questioned whether the pharmacological effects of these medicaments should, in fact, be acknowledged as the prime factor in this battle. In 1923, in an editorial, Lingui wrote that dentists should not rely on these medicaments, but rather upon mechanical enlargement of the root canal to the apical foramen, if possible, but to a minimum level of two thirds the length of the canal. (11). Among his general endodontic considerations, Englander states that mechanical cleansing and shaping is most important, with the use of certain medicaments as adjuncts. (12)

While not totally disregarding the important effects of intradental medicaments, recent emphasis has been placed upon intracanal preparation as the prime factor in proper endodontic treatment.

According to Schilder, intracanal preparation, cleansing and shaping, refers to the removal of all organic substrate from the root canal system, and the development of a purposeful form within the root canal for the reception of a dense and permanent root canal filling. (13)

Ingle and Zeldow mention an endodontic triad, and place canal enlargement first in that triad, before canal sterilization and canal obturation. (14)

Wiene, and Schilder, both state unequivocally that intracanal

preparation is the single most important factor of endodontic therapy. (5,13) While intracanal medicaments may still be an important factor, they are so, only in those root canals whose walls have been enlarged and debrided through proper preparation.

Although there exists minor discrepancies among endodontists as to exactly what constitutes proper intracanal preparation, there is universal agreement that the morphology of root canals serves as its basis.

A thorough working knowledge of the dynamics and anatomy of the root canal system is a prime prerequisite for successful treatment no matter what rationale, criteria, or principles the operator chooses to follow. Green states that morphologic knowledge aids the operator in tracing the root canal to its termination, thereby increasing his degree of success. The rare unsuccessful case falls in the category of the frailties of the human element of the operator, and the rebellion of the patient's cellular elements to injury.(15) To this end there has been a myriad of studies. With the aid of the radiograph, Pineda and Kuttler investigated 7,275 root canals and described such findings as straightness and curvature, ramifications and their locations, diameters at various levels, and location and form of the foramen at the root apex in virtually all human tooth types.(16) The conclusions of a much earlier study on root canal morphology by Mueller, while not giving percentages as did Pineda and Kuttler, can be applied to their study, and aid the clinician if kept in mind. Mueller concluded: 1. that there are no typical oval or conical shaped root canals; 2. each type of human tooth has variations in the shape, length, and width of the canals; 3. canals of one type of human tooth differ from canals of another type of

human tooth; 4. an obstruction in a canal may appear on a roentgenogram to be a denticle, when, in fact, it may be the formation of two canals; 5. the usual labiolingual or buccolingual roentgenographic view of teeth does not always present a true picture of the conditions that are present in the root canal.(17)

Weine, Healey, Gerstein, and Evanson, in a comprehensive study of the mesiobuccal root of the maxillary first molar, found a single root canal in 48.5% of the cases, two separate canals that merged prior to reaching the apex of the root in 37.5% of the cases, and two separate canals throughout the length of the root in 14% of the cases.(18) Results of a study by Skidmore and Bjorndal showed that the human mandibular first molar, contrary to popular beliefs, has as many as four root canals as found in 28.9% of the cases they studied.(19) They can have the converging and diverging patterns described by Weine, et al. Green examined 1300 single roots and concluded that with the exception of the maxillary anterior teeth, an individual root, from no matter which tooth, has more than one root canal a high percentage of the time.(20) Rankine-Wilson limited his study to mandibular anterior teeth, which universally had been taught to have only one root canal. His results showed that a divided canal occurred in 40.5% of the mandibular lateral and central incisors.(21)

Concerning themselves with the location of the apical foramen in relationship to the clinical radiographic apex, Levy and Glatt concluded from their study that the foramen deviates from the apex from 0.1 to 0.9 mm.(22) Kuttler said the terminal part of the root canal and the

tissues which surround it are the center of the most activity and the greatest concern in the treatment and filling of the root canal. His study of sectioned teeth examined under a microscope showed the deviation of the foramen from the apex; that the narrowest portion of the canal is at the cementodentinal junction; and that the foramen widens again as it proceeds apically beyond this location.(23)

Based on the knowledge of root canal morphology, the objectives of the design of intracanal preparation were given by Schilder:

1. The canal preparation should have a continuous taper.
2. The cross sectional diameter should be narrower at every point apically, and wider at every point coronally.
3. The canal preparation should flow with the shape of the original canal.
4. The apical foramen should remain in its original spatial relationship, both to bone and to the root surface.
5. The apical opening should be kept as small as is practical in all cases.(13)

Both Heuer, and Schilder, in discussing the biological concepts of cleansing and shaping, stress the importance of confining the endodontic instruments to the confines of the root canal, and the caution to be utilized so as not to push canal contents beyond the root apex and into the periapical tissues.(24,13)

Weine, Kelly, and Lio modified and greatly improved canal preparation in a study they performed on simulated root canals created in acryl-

ic blocks. The results of their study showed that following canal preparation with a standard K type file:

1. No preparation was completely funnel shaped from the orifice to the apex, but in fact, the narrowest portion of the canal is at the "elbow", a constriction coronal to the apex.
2. Every file, whether precurved or not, had a tendency to straighten out within the canal. During instrumentation, the file rode the inner portion of the preparation, between the canal orifice and the "elbow", the file rode the outer portion of the preparation, between the "elbow" and the apex, leaving what they termed a "morning glory effect".

They also used the term "apical zip" to describe the effect this straightening had on the shape of the apical foramen. They described a teardrop reshaping of the foramen. In order to prevent this zipping they suggest:

1. Files should be precurved, that is, a curve should be made, simulating the curve of the root as seen on the radiograph, prior to insertion into the canal.
2. Flutes on the file that rasp the outer portion of the preparation at the apical end should be removed with a diamond fingernail file.
3. Use a flared preparation.(25,5,26)

Hoog discussed case histories of endodontic failures caused by the failure of the operator to use precurved files, thereby enlarging, or perforating the apical foramen, as he calls it.(27) What he, in fact described was Weine's, et al., apical zip. Luks and Bolatin agree that it is undesirable to change the shape of the canal.(28)

The point of apical termination of the intracanal preparation has long been controversial. The controversy exists over whether to end the apical portion of the canal preparation at the radiographic apex, or whether to end the preparation short of the apex, and if so, how far short of the apex. It is the opinion of most experts, based on the findings of several studies, that the ideal point of termination of the canal preparation at the apex is at the cemento-dentinal junction, an anatomic landmark approximately 0.65 mm coronal to the root apex.(23, 5,29,10,30,31,32,33,34,35,36)

The adequacy, or inadequacy, of the prepared root canal is primarily dependant upon two factors, namely, the operator and his endodontic instruments. A good instrument is but an extension of the human hand. If the hand is developed to its fullest potential, both in dexterity and tactile sense, then a good instrument becomes a master tool capable of achieving the end result for which it was designed.(37) With this philosophy in mind, as stated here by Luks, and knowledge of the contents and morphology of root canals, the evolution and development of endodontic instruments has proceeded.

Among the modern instruments designed for intracanal use, the barbed broach is perhaps the crudest. This tapering metal instrument has pointed barbs deflected from its shaft. With gentle rotation of the

broach, these barbs snag pulp tissue in an attempt to remove the bulk of the canal contents prior to the actual canal preparation.

The rat-tail file, although seldom found in use today, has, at times, been used by some as the instrument of choice. This extremely flexible, highly soft steel instrument has disc-like cutting edges placed at right angles, running the entire length of the shaft. Due to the soft nature of this instrument, its dentin removing ability is very limited.

During canal preparation, the action of the Hedstrom file takes place upon withdrawal. The design of this instrument makes it an excellent planer of the canal wall. A tapering, spiralling trough is cut the length of the shaft. Since the trough is cut so deeply into the shaft there is always the danger of breakage when the cutting edge grasps the dentin wall. Any twisting or turning of the Hedstrom file is most definitely contraindicated, as this manipulation will certainly enhance the chance of breakage.

The cutting edges of the endodontic reamer are located at the angles of its square or triangular shaft, as seen in cross section. The cutting flutes are formed when the tapering shaft is spiralled by the manufacturer. The dentin removing ability of the reamer becomes evident when the instrument is turned screw-like into the canal, followed by a short outward pull of the instrument. Due to the curved morphology of most root canals, there is a great danger of canal perforation inherent in the use of the reamer. Used in straight root canals, or in the straight coronal portion of some canals, the reamer can be most efficient. While discussing the use and abuse of endodontic instruments, Sampeck

labels the file as being the "workhorse".(38) One of the big differences between the file and the reamer is the amount of flutes per unit of length of shaft. Although similar to the reamer in cross section, the file has more cutting flutes per unit of length of shaft than the reamer, 2.25 per millimeter and 1.5 per millimeter, respectively. Because most files are triangular in cross section, and have more cutting flutes along the length of the instrument than does the reamer, it is believed by many to be more efficient than the reamer at preparing the canal.

The cutting action of the file occurs upon withdrawal from the canal, and requires no rotation within the canal, hence the chance of perforation and breakage, is greatly reduced. It is felt by Luks, due to the thicker, square shaft of the reamer, that it is less flexible and more brittle than the file.(37) Contrary to this, Heuer feels that the reamer is more flexible.(24)

A cry from practitioners for a greater standardization of reamers and files by the manufacturers played an important role in the development of the endodontic instruments as we know them today.

Green made the claim that there was no uniformity in width of the cutting portion of the instrument as designated by size number; that there was no uniform taper, nor good balance between flexibility and stiffness; that there was no standards regulating resistance to breakage, sharpness of cutting edge, freedom from clogging, nor freedom from manufacturer's imperfections. Results of his study with a microscope showed that there was great variations in widths and tapers between sizes of instruments, and he concluded that the lack of good quality control and

a uniform standardization of reamers and files made good endodontic treatment far too difficult.(39)

The Second International Conference on Endodontics established a guideline for which endodontic instruments were to be standardized.

They wanted:

1. A formula for the diameter and taper for each size instrument.
2. A formula for graduated instruments from one size to the next size.
3. A new instrument numbering system based on the diameter of the instrument.

A numbering system from 10 to 140 was created based on the diameter of the instrument in tenths of a millimeter. The increase in size from instrument to instrument was set at 0.05mm from size 10 to 60, and 0.1mm from size 60 to 140. The taper of each instrument was established at 0.01875mm per millimeter, based on the formula

$$\frac{D_2 - D_1}{\text{Distance between } D_2 \text{ and } D_1} = \frac{0.3\text{mm}}{16.0\text{mm}}$$

D_2 represents the diameter of the instrument where the flutes begin on the shaft, and D_1 represents the diameter at the tip, a point 16mm down the shaft.(40)

Having applied a stiffness test, cold bend test, and torque test to carbon steel reamers and files, Craig and Peyton found that there is increased stiffness in the root canal instrument as the size of the instrument increases. The larger the size of the instrument, the less

resistance to breakage exists. Finally they concluded that bending or twisting of the instrument, especially if the tip is tightly wedged in a constriction of the canal, will cause fracture of the instrument.(18)

Standardization of root canal instruments has been one of the greatest improvements in the history of endodontics. It has reduced much of the existing frustration of clinicians.

In 1964, with the claims of making endodontic canal preparation even less frustrating, much easier, less exhausting, and safer, the Micromega Co. of Switzerland introduced a new endodontic instrument, the giromatic. The giromatic is an engine powered handpiece, in which are locked canal explorers, files, reamers, or broaches that have been standardized by the same system as are the finger manipulated instruments discussed above. The giromatic system prepares the canal walls by making reciprocating 1/4 turns within the canal, while the operator moves the handpiece 2mm in an push-pull motion, thus removing dentin.

Early use of the giromatic was limited to Europe, and it was not introduced in the United States until 1967, where it was met with much skepticism and controversy. Much of the early writings on the use of the giromatic system were highly subjective.

Castagnola and Alman, in Austria in 1965, having tried the giromatic, wrote that it worked well in their hands.(41) Drum in Berlin in 1966 used the giromatic on 127 teeth and said that he was pleased with it.(42) Perret, in France gave his subjective views on the advantages and disadvantages of the new system.(43) Hennicke, in Germany, was first to attempt to relate hand instrumentation to the giromatic system. He found the new system saved time in the hands of those not yet fully

trained in the use of the hand instruments.(44) Frank criticized the claims of the American distributor of the giromatic who stated that the quick, easy, and efficient giromatic saves worry about the patient aspirating or swallowing the instrument since it is latched into the hand-piece. The timesaving comes from the disregard for the established principle of maintaining an aseptic technique with the use of a rubber dam, which proponents of the giromatic apparently felt was unwarranted. Although Frank found no ledging or perforating of the canal wall with the giromatic, he was unable to penetrate to the apex in every case, and had to rely on the conventional hand instrument to do so.(45) Rowe felt that the giromatic broach, the only existing giromatic instrument in 1966, was unlikely to enlarge the canal sufficiently, but that it would facilitate the removal of pulp debris.(46) As was mentioned, the giromatic broach was the only instrument available for this system for several years, and it was not until the early 1970's that the armamentarium included girofiles and later reamers.

The controversy over the new invention forced researchers to evaluate and reevaluate the intracanal preparations created by both the conventional hand instrumentation, and the giromatic techniques. It must be kept in mind, that although the adequacy of canal preparation by the various techniques was in question, the basic endodontic principles for instrumentation were not. The principles affecting the evaluation of canal preparation are:

1. The canal preparation should have a continuous taper toward the apex.

2. The preparation should follow the original shape of the canal.
3. The overall shape and location of the apical foramen should remain unaltered.
4. The use of an irrigant should be liberal.
5. Instruments should remain within the confines of a canal.
6. Use a smaller to larger size sequence of instruments.
7. Remove all organic and inorganic pulpal debris.

Haga in 1968 examined the thoroughness and type of preparation resulting from hand instrumentation of 131 extracted human teeth. He found that even with thorough filing, there was always a channel of tissue and canal wall that went untouched, and this was generally found at a level 6mm from the apex, where the curve of the canal was greatest. (47)

Laws, in 1968, set out to evaluate the giromatic as an aid in facilitating the routine, "exhausting" hand preparation of root canals. Using 54 extracted teeth, and a sequence of size fine to size large broach, he found that the instrument located the orifice and penetrated straight canals easily, but holding the handpiece resulted in the loss of tactile sense, and penetration of curved canals was, therefore, much slower and more difficult. He found that the broaches were unable to reach the apex in all cases, but attempts with hand reamers were successful. Laws also found that not all canal irregularities were removed by the giromatic broaches. He did conclude that for the practitioner who is interested and does a reasonable number of endodontic cases each year,

the use of the instrument should offer a savings of time and effort, but that this method is good only for single rooted teeth with large, straight canals.(48)

With 120 extracted mandibular anterior teeth, Gutierrez and Garsia evaluated canal preparation using conventional files and reamers. Their results showed that pulp horns were poorly eliminated; that "fin-like" projections of canal walls containing tissue, remained untouched; that preparation of curved canals resulted in a constriction near the junction of the middle and apical thirds of the canal, and a widening again near the apical foramen; and on teeth with an apical curve, use of a large instrument resulted in a deviation from the anatomic root canal.(49)

Comparing the giromatic system to the conventional system, Molven studied the penetration of the mesiolingual and mesiobuccal root canals of 40 mandibular molars. The study indicated no discernable difference between the giromatic broach size fine and the Kerr size 15 file, in penetrating the canal to the apex. The results showed that 19 root canals were unpenetrable by either instrument, and an approximately equal number of apices were reached by one instrument, when the other had failed to do so.(50)

On 33 extracted mandibular incisors, Vessey compared the effects of conventional files and reamers. After instrumenting the canals until they felt smooth, and clean white dentinal shavings could be removed from the canal, he studied cross sections cut at levels 2mm, 3mm, 4mm, and 5mm from the apex. The results showed no significant difference between a file used in a reaming action and a reamer used in a reaming action, but there was a significant difference between a file used as a file, in

a rasping action, and a reamer used in a reaming action. The file used as a file produced many deviations in both buccolingual and mesiodistal directions, whereas, the reamer produced the round canal preparation that Vessey desired.(51) It should be noted that a reamer will always give a rounder preparation than a file, but if maintenance of the original shape of the canal is desired, then a round preparation is not desirable, since no root canal is perfectly round in cross section. Only the maxillary central incisor approximates a round cross section.(47)

In a comparison of the dentin removing ability of three hand instruments and two motorized instruments, Molven used 4 one and a half millimeter thick slices taken from the cervical portion of roots of 90 pre-molars, and prepared the canal in each slice according to their accepted techniques. The results showed that the desired taper shape was least pronounced with the giromatic, and that the giromatic broaches were inadequate for removing dentin. The Anteos and Kerr type K files gave the best results.(52)

Since studies had shown that the giromatic broaches were adequate in removing the bulk of the pulp tissue, but inadequate in preparing the root canal properly, girofiles were added to the giromatic armamentarium. These instruments were also manufactured to conform with the recommendations of the International Standards Organization.

In order to test the girofile against the hand held file, Harty and Stock made vertical exposures of the mesial root canals of 51 mandibular first and second molars. One mesial canal was prepared initially with a broach followed by a sequence of girofiles. The other canal was prepared with a hand held Hedstrom files, again using a sequence of suc-

cessive file sizes. Results after comparing these systems show no statistical difference in penetration of the root canal, time needed to prepare the canal, size of final instrument used in preparation, or mechanical efficiency in the preparation of curved canals.(53)

O'Connell and Brayton made silicone impressions of canal preparations with the giromatic system and the conventional system. The canals of 42 extracted teeth were pared to 1mm short of the apex, and silicone injected. The tooth was decalcified and the impressions studied. Fifty-one of 88 canals (57.9%) instrumented by conventional type K files received a grade of excellent, and only 30 of 84 canals (35.7%) prepared by girofiles received such a grade. Both systems had a high number of unsatisfactory grades in the category of elimination of morphologic aberrations. O'Connell and Brayton admit that although the results are too subjective, and the sample size too small, it appears that the conventional system of hand held instrumentation was superior to the automated instrumentation of the giromatic.(54)

With the invention of the scanning electron microscope, scientists have been able to explore our world in a more intimate manner than ever before. Nothing has escaped the scrutinizing eye of the SEM, and that includes the field of endodontics.

Mizrah, Tucker, and Seltzer used the SEM to examine canal preparation with different instruments. They found that the giromatic broach left large quantities of tissue in the canal in a homogenized, coagulated film along the canal walls. When the giromatic broaches and Hedstrom files were both used there was less debris, but more debris clung to one wall than to the other walls. Except for the giromatic broaches,

conventional files showed the largest quantity of debris along the walls, and dentin filings were densely packed at the apex. Of all the systems tested, the cleanest walls were found in those canals that were instrumented by files followed by corresponding sizes of reamers.(55)

Using a light microscope, Klayman and Brilliant studied the efficacy of serial preparations to giromatic preparations. A serial preparation is made by preparing the apical few millimeters of canals with conventional files, and enlarging the coronal portion with a Gates Glidden drill. The Gates Glidden drill is a long shanked bur which rotates in a standard low-speed dental handpiece. Their study showed that at a level 1mm from the apex, only 26.09% of the canals prepared with the giromatic reamers were clean of all debris, while 72.34% of the serially prepared teeth were clean of all tissue. At all levels checked, the serial preparation scored better than the giromatic at removal of tissue.(56)

Walton was yet another who studied the effectiveness of different methods of enlarging the pulp space, but he added a unique dimension to his study. He designed an in situ experiment, whereby 91 root canals of 52 teeth were prepared by three methods, reaming, filing, and stepping back. Following canal preparation, the teeth were extracted, and prepared for histologic slides. Examination of the slides showed that all three methods left some tissue in the canals, even though they were instrumented until clean, white dentinal filings were found on the instruments, and the walls of the canals felt smooth. A filing action was found to be slightly better than a reaming action in curved canals, since reaming always seemed to miss one wall. The step back method was found

to be significantly better than the other two methods at removing tissue and enlarging the canals. The step back method incorporated reaming with files until a final size was established at the apex, then filing 1mm coronal to this apical length with the next largest sized instrument, and repeating this "step back" with the proper sequence of instruments.(57)

Several techniques have been proposed for the use of the giromatic in the preparation of root canals, including one which incorporates both the giromatic and conventional hand instrumentation (58), but the technique used by most proponents of the giromatic is that suggested by Sargenti.

Over the years, Sargenti has modified his suggested technique such that he feels it is now "fundamentally" the same as using hand operated instruments.(59,60,61) In his technique, he suggests the use of both the giromatic handpiece and the conventional dental handpiece. The giromatic instrument is used in the giromatic handpiece first, producing reciprocating 1/4 turns, and then in the conventional handpiece, which produces a complete rotation of the giromatic instrument. The full rotation of the instruments is done only in the straight portion of the canals, never in curved portions. This is done so as not to cause a ledging or perforation of the canal walls. Gradually increasing sizes of instruments are used, as with the conventional technique, but there are several major differences between these techniques, differences that will be discussed later.

While researchers worked arduously to establish which technique and which instrument worked best at removing the contents of the root canal,

and which instrument was best suited for enlarging the root canal, others were studying the effects of instrumentation on pulpal and periapical tissues.

In 1929, Blaney made observations about tissue reactions that occurred within root canals and about root apices of teeth following pulp removal. He made the observation that the tissue found in accessory canals was the same tissue found in the periodontal membrane. He noted, that over a period of time following root canal therapy, there was necrosis of remaining soft tissue within the canals, and resorption of the canal walls. He found a "migration of cementoblasts" into the root canal which he felt laid down a cementum-like tissue in an attempt to repair the resorptive areas. He also felt this cementum-like tissue was active in repairing the cementum resorption adjacent to the apical foramen. (62)

In 1963, Nyborg and Halling compared the effects of partial pulp extirpation by Anteos reamers and Hedstrom files. They discovered that there was most often an inflammatory cellular infiltration. The remaining stump of pulp tissue had in some cases become necrotic with impacted debris, lost its central core, or had become twisted in the canal, as was the case most often when reamers were used. In canals with large denticles attached to the walls, the pulp stump apical to the denticles was vital and well preserved. (63)

Sekine, Machida and Imanishi tested the tissue reaction to pulp extirpation and pulp amputation in the middle 1/3 of the root canal. Following the tissue removal, the open portions of the canals were filled with a calcium hydroxide antibiotic containing compound they termed "New

Paste". This filling material obviously had an effect on the tissue reactions, but these reactions were, in part, caused by the instrumentation. In the group where the pulp was extirpated "completely", histologic sections taken from 2 to 879 days, showed an ingrowth into the canal of granulation tissue from the periodontal membrane, and a closing off of the canal at the apex by cementum deposition. Those teeth where extirpation was not total showed apical cemental deposition as well. Within the canal secondary dentin formation ranged from slight apposition to denticle formation. Complete dentin bridging of the canal occurred in some cases. The reaction of pulp remnants where extirpation was incomplete ranged from mildly acute to suppurative necrosis. Resorption of dentin and cementum almost always was complete. Of the teeth where the pulp was amputated in the middle 1/3 of the canal, a high percentage became clinically symptomatic within a short period following instrumentation. After experiencing various degrees of inflammation, they found complete healing of the remaining pulp tissues in most cases, and clinical symptoms ceased. Healing was seen to begin at the apical portion of the stump, and spread coronally, where it was in contact with the "New Paste".(64)

Following instrumentation, Erausquin, Muruzabal, DeVoto and Rickles purposely overfilled root canals of Wistar rats and made observations on the pathologic state of the periodontal tissue surrounding the overfilled area. Although they found necrosis in the periodontal membrane and adjacent alveolar bone and cementum, they felt that this necrosis was induced by mechanical trauma.(65)

Engstrom and Spangberg reported their findings on a study where 12

contralateral pairs of vital teeth were treated by partial pulpectomies with Hedstrom files. One tooth of each pair was filled with calcium hydroxide coronal to the site of partial pulpectomy, while the other of the pair was filled with gutta percha and chloropercha. Once again, these filling materials certainly had an effect on the state of the pulp stump, but some of the results were similar to those studies where no filling material was used. Of the teeth where the site of severance of pulp tissue was 3.5mm or more, 75% were considered endodontic failures. Internal resorption was evident in several cases, and some hard tissue repair was observed in 3 of the cases considered endodontic failures.(66)

Sinai, Seltzer, Soltanoff, Goldenberg and Bender ran a series of experiments to evaluate how the pulpal and periapical tissues reacted to all phases of endodontic instrumentation. In 1967, they observed the effects of pulp extirpation on 24 teeth of Rhesus monkeys and 13 human teeth. Upon examination of block sections they found that neither the barbed broach nor the Hedstrom file removed all the tissue from within the canals. The remaining stump of pulp tissues in the monkeys showed an acute inflammatory reaction by one week, acute or chronic inflammation by one month, and necrosis by six months. The periapical tissues reacted in a similar manner, from acute to chronic inflammatory changes, but tended to show signs of repair by six months. Of the two human block sections examined, the pulp stump and periapical tissues of one tooth had returned to normal, while the tissues of the other remained necrotic by the end of one year following extirpation.(67)

The following year they reported the findings of their study on

the effects of instrumentation on periapical tissues. In part one, they instrumented short of the apices several millimeters. By one week they found dentine chips packed against the remaining pulp tissue. Polymorphonuclear leukocytes, diagnostically found in an acute inflammatory state, infiltrated the periapical tissue adjacent to the root apex. Internal resorption had occurred in the apical 1/3 of the canal. The reaction of the 42 day specimens ran from chronic cellular infiltration of lymphocytes, monocytes, and macrophages in the pulp stump with an edematous widened periodontal ligament to a large periapical radiolucency on an x-ray that upon histologic examination showed granulation tissue filling the apical foramen, granulation tissue surrounding the apex, and resorption of cementum and dentin in the vicinity. By 90 days resorption and repair of resorption by newly formed cementum was evident. The 180 day specimens showed chronic inflammation in the canal contents, resorption and repair in the apical area, with granulomatous tissue formation and new bone trabecular formation in the periapical tissues.(68) The next phase of their experiment was to instrument beyond the apex, and observe the results. Four to seven days after instrumentation they found an acute inflammatory response had taken place. The histologic sections showed dentine debris in marrow spaces 15mm beyond the apex. After 42 days, epithelium was seen proliferating into the root canal and the granuloma that had formed adjacent to the apex. Root and bone resorption was also evident. By 180 days the granuloma and proliferating epithelium were still in evidence, and in some specimens liquefaction necrosis had taken place. The 270 day specimens showed that although cementum and dentine resorption had ceased, there was no apparent

repair taking place, and the chronic inflammatory cells persisted.(69)

Using files to prepare 32 root canals in 4 dogs, Davis, Joseph, and Bucher studied the reactions of pulp and periapical tissues where the distance from the apex to the termination points of instrumentation and obliteration varied. Where the canals were instrumented to a working length of 0.1mm to 0.8mm from the apex, and filled approximately 0.8mm from the apex, the success rate was good, although there did occur some liquefaction necrosis in untouched terminal accessory canals. Granulomas and new bone formation were observed in the periapical areas. Where the canals were prepared to the apex and filled 3 mm short of the apex they found bone loss, and either liquefaction necrosis or a mild inflammatory state. Good healing was generally found in the cases that were instrumented beyond the apex, but filled short of the apex. Healing was generally found to be one of three types:

1. The apex was plugged by dentine fillings and covered with secondary cementum so that there was no communication between the dentin plug and the periodontal ligament.
2. Bone deposition partially filled the hollow root canal space.
3. There was the formation of a complete "attachment apparatus" within the root canal space, consisting of cementum, periodontal ligament, and alveolar bone.(70)

MATERIALS AND METHODS

In order to study the tissue reaction to intracanal instrumentation at various time intervals, 180 days, 42 days and 3 days, three adult male Macaca mulatta monkeys, having a permanent dentition were obtained. The monkeys were quarantined for a period of thirty days, observed and tested for any existing chronic disease or disorder that could effect the results of the experiment.

Following the quarantine period, their chests were shaved, and a dye tatoo was placed on the exposed area and their weights recorded. Each monkey received a different tatoo, G1, G2, and G3, corresponding respectively to the 180 days, 42 days and 3 days time intervals. The individual monkey will each be referred to as G1, G2, or G3. At this first session, full mouth periapical radiographs were taken.

In order to handle the monkeys, immediately prior to each experimental session, the monkey to be used that session was administered 0.6 cc of Sernylan (phencyclidine hydrochloride)^{a)} intramuscularly and 1.0cc^{b)} of Atrosed (atropine sulfate) subqutaneously.

According to the manufacturer, the principal pharmacological effect of Sernylan is the depression of the central nervous system. It

a) Bio-Ceutic Lab., Inc., St. Louis, Mo.

b) Burns-Biotec Lab., Oakland, Calif.

also has anesthetic, analgetic and sympathomimetic effects. Even though the animal is incapacitated or completely anesthetized: (1) simple reflexes such as the patellar, palpebral, corneal and pupillary are not completely eliminated; (2) the eyes may remain open; (3) muscle tone is increased in most cases, but a decrease in tonus may occur; (4) respiration and blood pressure are not usually depressed. In primates the effects produced are: reduced response to environment with reduced aggressiveness, recumbent immobilization without flaccid paralysis, catalepsis, and analgesia, depending on the dosage employed. A patent airway must be maintained should excessive salivation become evident, and because of the depression of the central nervous system, bradycardia is a possible side effect.

Atrosed (atropine sulfate) is a cholinergic blocking agent. In the small dose used, it acts to stimulate the respiratory mechanism, and to nullify any bradycardia or decline in blood pressure.

It became necessary, for analgesic purposes, to administer sodium phenobarbital prior to the initiation of endodontic therapy. Sodium pentabarbital^(a) is a long acting barbiturate whose principal action on the cerebral cortex is depression of the central nervous system. The level of depression desired for the purposes of the experiment was that of surgical anesthesia. An initial dose of 2.0cc of sodium phenobarbital was injected intravenously, and supplemented with additional injections if it became necessary to maintain the desired level of anesthesia.

a) W.A. Butler Company, Columbus, Ohio

Forty-four teeth comprising 75 root canals were instrumented for the experiment. Two teeth per monkey were used as controls, and no operations were performed on these teeth. Where applicable, established conventional endodontic principles were adhered to throughout the study.⁽⁵⁾ As sterile a field of operation as was possible was maintained. Occlusal or incisal access to the pulp chamber was made with a high speed handpiece using a #557 bur. Estimated working lengths were obtained from preoperative radiographs and final working lengths were confirmed by radiographs of the teeth with #10 or #15 conventional files having been placed in each canal to be instrumented. Silicone adjustable stops were utilized with a reference point, in order to establish the final working lengths, and used throughout the instrumentation of each root canal.

Instrumentation by the conventional, hand held technique was achieved by the use of type K files.^{a)} Instrumentation by the giromatic system was achieved by the use of a giromatic contra-angle^{b)}, and girofiles.^{c)} During the instrumentation, sterile water was used frequently as an irrigant to flush out the canal contents. Instrumentation of each canal began with a size 10 instrument and proceeded until clean, white dentinal shavings were found in the instrument flutes throughout the length of the instrument, and the canal was considered enlarged

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- a) Star Dental Mfg. Co., Conshohocken, Pa.
 - b) Micro-Mega, Lyon France
 - c) Medidenta Co., Woodside, N.Y.

enough and prepared adequately enough to receive a root canal filling. All instruments were precurved to imitate canal curvature prior to their placement into the canals, and to facilitate adequate canal preparation. A tapering, flared preparation was made in all canals.(5) Having the final instrument used for preparation in the canals, a radiograph was taken to verify the established working length. A final irrigation with sterile water was performed, and the canals were dried with the use of sterile cotton pellets and paper points. The access openings were closed by placement of amalgam. Until the day of sacrifice for the respective monkey, they were given a diet of vitamin and protein biscuits and water.

Both maxillary and mandibular arches, and all types of teeth, molars, bicuspid, cuspids and incisors, were used on all three monkeys. Six categories were tested, corresponding to the system of instrumentation used and the distance of instrumentation relative to the radiographic apex. The categories were: conventional system approximately 1mm short of the apex (CO); giromatic system approximately 1mm short of the apex (GO); conventional system 3mm to 4mm short of the apex (CS); giromatic system 3mm to 4mm short of the apex (GS); conventional system at least 1mm beyond the apex (CB); and giromatic system at least 1mm beyond the apex (GB). The number of teeth on each monkey and the number of root canals prepared in each category are given below.

<u>Monkey</u>	<u>No. of teeth</u>	<u>No. of canals in each category</u>					
		CO	GO	CS	GS	CB	GB
G1	20	10	9	6	7	3	5
G2	12	3	3	2	3	2	3
G3	12	3	2	4	6	2	2
Total	<u>44</u>	<u>16</u>	<u>14</u>	<u>12</u>	<u>16</u>	<u>7</u>	<u>10</u>

At the end of the respective time periods, 180 days, 42 days, and 3 days, the monkeys were sacrificed. Beuthansta-D^{a)} a highly concentrated solution of sodium pentobarbital was injected intravenously, and death was instantaneous. Both maxillary and mandibular arches were surgically resected, radiographed, and trimmed for tissue fixation. The amalgam occlusal sealings were removed in order to facilitate a better fixation of tissues, and the specimens were placed in a 10% formalin solution for one week until fixation had occurred. Following fixation, the specimens were rinsed in water and placed in a solution of formic acid and sodium citrate until decalcified. This decalcifying period took approximately 5 weeks. The decalcified block sections were then trimmed so as to facilitate histologic sectioning of individual teeth or individual roots of multi rooted teeth.

The specimens were mounted in paraffin and histologic sections were cut to a thickness of 6 microns. Forty-two sections of each specimen were mounted on glass slides and stained. The stains used were hema-

a) Burns-Biotec Labs., Oakland, Calif.

toxylin and eosin, and Mallory's aniline blue. The slides were studied under a light microscope, using 100X and 440X power magnification. The findings were recorded.

RESULTS

All teeth that served as controls for the study were caries free and normal periapically throughout the period of study. Histologic examination of the contents of the root canals and periapical tissues of the control teeth showed them to be normal and healthy, confirming the findings of others. (71,72,73,74,75,76,77)

The pulp was found to have four characteristic zones. The most peripheral zone, the odontoblastic zone, contains the mononuclear odontoblasts, lying adjacent to the more eosinophilic staining predentin matrix. The odontoblasts were arranged in layers several cells thick. Inside the odontoblastic zone is located the cell free zone, also termed the zone of Weil. Capillaries and nerves, primarily unmyelinated nerves were observed passing into this layer. This narrow zone was located outside the cell rich zone. The cell rich zone contained numerous cells, both in type and number. The multipotential mesenchymal cell was seen in most sections. The fibroblasts appeared as the most common cell present throughout the pulp. These stellate or spindle shaped cells appeared to be interconnected by cytoplasmic extensions. The fibroblasts were situated among the collagen fibers which were found in varying degrees of density in the inner zones of the pulp. There was a higher concentration of cells coronally, and fewer numbers of cells were observed in more apical sections. The opposite was found to exist for the collagen fibers. A denser accumulation of fibers were located apically, and a looser arrangement of fibers was seen coronally. Histiocytes

were occasionally observed, usually in the vicinity of vessels. What appears to be pericytes could be seen in the thin walls of capillaries. The innermost zone of the pulp is the central zone. It contained the identical cells found in the cell rich zone, but it contained a core of much larger vessels and myelinated nerves. Nerves in the periodontal tissues could be seen to merge prior to entering the apical foramen. They followed the course of the larger arteries and veins, and like these vessels they arborized as they proceeded coronally.

Densely arranged collagen fibers constituted the bulk of the periodontal ligament. Many of the fibers were seen to run from the alveolar bone to the apical cementum while others appeared to form a sling below the root apex. Fibroblasts were numerous throughout the periodontal ligament and by far were the most common cell found. The cell rests of Malassez, which appeared as strands or oval groupings of epithelial cells were observed in the periodontal ligament at all levels of the root. A rare cementicle was observed near the root apex. The alveolar bone marrow spaces were almost entirely cell free, and contained large globules of fat. There was some evidence of osteoclastic and osteoblastic activity in the supporting bone, but this was not a common finding.

The status of the pulp stump and periapical tissues following instrumentation ranged from normal to necrotic, from mild inflammation, to severe inflammation, from acute inflammation to chronic inflammation, from tissue destruction to tissue repair.

The three day specimens, having been instrumented three to four millimeters short of the radiographic apex by either the conventional or the giro-matic method, showed similar results, that is, a mildly acute inflammatory

state. Tissue debris comprised mainly of torn fibers. A few extravasated erythrocytes and cellular remnants could be seen in the instrumented portion of the root canals. Calcified debris, probably dentin filings, were packed against the pulp stumps. A mild infiltration of polymorphonuclear leukocytes (PMN), the cell type associated with acute inflammation, was observed in the otherwise normal pulp stump tissue. Periapically the tissues appeared relatively normal except for the increase in vascularity and a small number of acute inflammatory cells. (Table 1)

The forty-two day specimens in the three to four millimeter short of the radiographic apex category showed some histologic differences between the methods of instrumentation being compared. The pulp stumps of the teeth instrumented by the conventional method appeared to be in a moderate inflammatory state, and the periapical tissues were found to have a very small periapical abscess. The pulp stumps and periapical tissues of the teeth instrumented by the giromatic method appeared to be in a more severe inflammatory state. (Table 2)

One hundred eighty days following conventional instrumentation three to four millimeters short of the radiographic apex, scattered chronic inflammatory cells were observed throughout the pulp stump tissue, and packed against this mildly inflamed tissue were dentinal filings. The periapical tissues of these specimens either appeared normal with slightly widened periodontal ligament spaces, or displayed chronic periapical abscesses. One specimen had developed a small periradicular abscess in the periodontal ligament at the middle root level. This pathologic area was separated from the periapical abscess by normal appearing tissue. Only one specimen in this category displayed an abscess of an appreciably large size. In this specimen, the lesion

had extended coronally along one side of the root. In the chronic lesions of all the one hundred eighty day specimens, there was definite evidence of capillary budding among the chronic cells.

The pulp stump and periapical tissues of specimens prepared three to four millimeters short of the radiographic apex by the giromatic method showed similar results to the conventionally prepared specimens for the same one hundred eighty day period. (Table 3)

The three day specimens of teeth instrumented one millimeter short of the radiographic apex by both methods displayed similar findings within the root canals, but a difference in severity of inflammation of the periapical tissues. The pulp stumps were found to be relatively normal, or have a severe acute inflammatory condition. The specimens having relatively normal pulp stump tissues had relatively normal periapical tissues. The severe inflammatory state in the pulp stump tissues following instrumentation by the conventional method was also found in the periapical region. The specimen instrumented by the giromatic method, having a severe inflammatory state in the pulp stump tissues, had more moderately inflamed periapical tissues. (Table 4)

The forty-two day specimens in this category showed similar results when comparing the two methods. The difference was evident in the periapical tissues of the teeth instrumented by the conventional method. The inflammation of these periapical tissues appeared more severe as compared to a moderate amount of inflammation in the periapical tissues of the giromatic specimens. (Table 5)

Three specimens prepared one millimeter short of the radiographic apex by the conventional method and observed one hundred eighty days following

preparation, showed no inflammation of the stump tissue. Two of these specimens had normal appearing periapical tissues. The remaining specimens showed mild to moderate inflammation of the stump tissue. All specimens had dental filings packed at the apical portion of the canal coronal to the stump tissues. With the exception of the two normal appearing specimens, some degree of inflammation was noted in all specimens. A large periapical abscess was found extending deep into the alveolar bone on one specimen.

Mild to moderate inflammation, as denoted by the number and concentration of chronic inflammatory cells present, was observed in the apical portions of all specimens prepared by the giromatic in this category. Two specimens whose stump tissues were lost in histologic preparation showed normal appearing periapical tissues. Generally the periapical tissues of the remaining specimens were severely inflamed, displaying prominent abscesses.

(Table 6)

The three and the forty-two day specimens of teeth instrumented beyond the radiographic apex displayed similar findings when comparing the two methods. Moderate to severe infiltration of tissue debris by acute inflammatory cells was the general finding. As the test period proceeded from three days to forty-two days, severe acute inflammation leading to periapical abscess formation was observed in specimens of both methods. (Table 7 & 8)

One hundred eighty days following instrumentation beyond the radiographic apex conventional and giromatic specimens were found to have relatively clean canals. One conventionally instrumented canal was filled with extravasated erythrocytes. In the periapical tissues of the specimens in this category, severe inflammation was the general finding. Extensive tissue destruction was observed bordering large periapical abscesses. Alveolar bone

resorption was notably extensive. (Table 9)

DISCUSSION

In every biologic study the sample size is most important. Obviously, the greater the sample size, the more significant the results. In all in vivo studies unforeseen factors develop which influence the sample size. Several unforeseen factors in this study had a limiting effect on its sample size.

Attempts to obtain access to the dental pulps of the rhesus monkeys were halted when the animals began to hyperventilate. Although an air cooling spray accompanied the drilling, a severe painful response was elicited. It was necessary to administer a general anesthetic with the use of a barbiturate, so that the animal would be spared any further discomfort. Because of the life threatening reaction that can occur while keeping an animal under general anesthetic for prolonged periods, a working time limit of eight to ten hours was established. A shorter working time meant less teeth would be instrumented.

The sample size was again reduced when girofiles separated in the root canals of two teeth instrumented by the giromatic method. Attempts to retrieve these girofile fragments proved futile. Perhaps some instrument breakage is to be expected with the giromatic method, contrary to the manufacturer's claims. This breakage of the instrument in the canal probably is due to the reaming action of the instrument. The mechanical turning of the instrument tends to lock the cutting flutes into the canal wall and the manual pulling motion of the locked instrument could easily strain the metal beyond its

tensile strength limits.

Other specimens were lost due to errors in histologic preparation. Improper sectioning or embedding of some specimens made portions of the slides impossible to evaluate.

The clinical situation can arise where the root canal is so constricted that penetration of the endodontic instrument to the desired working length is impossible. Instrumentation several millimeters short of the apex, as in this situation, might allow a vital pulp stump to remain in the apical portion of the canal. Improper angulation in radiographic technique, improper interpretation of radiographic root lengths, or failure to acquire instrumentation working lengths radiographically may also result in instrumentation short of the ideal level.

These errors might also allow vital pulp stump tissue to remain in the canals. For these reasons it was decided to compare the methods of instrumentation to a level three to four millimeters short of the radiographic apex.

As was discussed in the review of related literature section, most endodontic authorities believe that the ideal termination of the root canal preparation is at the cementodentinal junction. (5,13,23) This level is clinically estimated to be one millimeter short of the location where the canal exits the root as viewed on the radiograph. (5) For this reason, canals were instrumented to the level one millimeter short of this location.

Improper angulation in radiographic technique, improper interpretation of radiographic root lengths, or failure to establish proper instrument working lengths radiographically also may result in the inadvertent instrumentation beyond the apex of a tooth. Failure to verify corrected working lengths radiographically may have the same result, overinstrumentation. For these

reasons, instrumentation beyond the apex by the two methods also was tested.

Both the conventional K-type files and the girofiles, while performing their endodontic functions, served as a source of irritation to the tissues of the pulp and periapex. The hand manipulated K-type files were placed in the canal to the desired length, a push motion, and withdrawn against the walls of the canal, a pull motion. The giromatic system incorporates a manual push-pull motion along with a mechanical reciprocating, turning motion.

These two instruments severed the soft tissue at some level, thereby initiating an inflammatory response. Understanding the dynamics of inflammation will aid in the interpretation of the results.

Inflammation is a defense mechanism of the body in response to some irritating agent. In this study the endodontic instruments and the tissues they destroyed served as the irritating agents. The severing of vital tissue propagates further tissue destruction due to the release of cytolytic elements of the destroyed cells. Generally, the amount of inflammation produced in response to the irritation is proportional to the concentration of the irritating agent. In this study, the greater the amount of tissue destroyed by either the conventional or the giromatic method, the more inflammation that was produced. The comparative aspect of this study stems from this premise.

The teeth instrumented by either method to a level three to four millimeters short of the radiographic apex all displayed mild acute inflammation in their pulp stumps after three days. There were, however, some subtle differences in the findings which could have had an effect on the state of these tissues, had the test period been longer.

The teeth that were instrumented by the conventional filing method

tended to have far less tissue debris remaining in the canal after instrumentation than did the teeth instrumented by the giromatic method. This was the general finding in specimens of all categories. (Fig. 1) Tissue remaining in the canals prepared conventionally tended to be packed with dentin filings in the apical third of the canals. Collagen fibers appeared to separate the debris from the other pulpal cells. The pulp stump appeared normal, with the exception of a scant number of polymorphonuclear leukocytes, the polys. In comparison, canals instrumented with the giromatic method tended to have tissue debris packed throughout their lengths. There were no fibers separating the debris and dentin filings from pulp stump tissue. There was also a greater infiltration of acute inflammatory cells in the pulp stump tissue.

Similarly, subtle differences were found in the periapical tissues. The periapical tissues of teeth filed in the conventional manner showed an increase in vascularity, but otherwise appeared normal. The periapical tissue of teeth filed with the giromatic method had an infiltration of polymorphonuclear leukocytes. In one tooth, polys were observed in the periodontal ligament adjacent to a lateral canal.

The tissue debris found in the canals was comprised of torn segments of collagen fibers mixed with intact cells and remnants of destroyed cells. Much of the debris appeared rather amorphous. Some peripheral sections of the canals showed clumpings of dark staining cells having large nuclei. These cells were odontoblasts that had remained untouched by the endodontic instruments.

Severance of tissue from its nutritive source leads to cell death, and the cytolytic chemicals released by dying cells can potentiate further cell

destruction. If the remnants of dead cells can serve as a nutritive source for microorganisms, then we must also assume that it is detrimental to allow tissue that does not have the capacity of maintaining a healthy state to remain in the prepared root canal.

In comparing the canals prepared by the tested methods, it can be hypothesized that since the giromatic method tended to leave more tissue in the canals, then a greater inflammatory state would be expected in the pulp stumps and periapical tissues over a longer period. This hypothesis was proven by the results of teeth instrumented forty-two days prior to sacrifice.

Forty-two days following instrumentation three to four millimeters short of the apex by the conventional method, moderate inflammation was noted in the pulp stumps. Dentinal filings were packed against the pulp stump tissue. The periapical tissue had developed a small periapical abscess, a small concentrated area of polymorphonuclear leukocytes encircled by mixed acute and chronic inflammatory cells.

A more severe inflammation existed in the apical portion of canals instrumented with the giromatic. Polymorphonuclear leukocytes were observed concentrated apical to the debris. Tissue left in a lateral canal also contained polys. A small periapical abscess with a necrotic center was adjacent to the apex of this tooth. Within the concentrated area of polymorphonuclear leukocytes, dentinal filings and some necrosis was observed. This inflamed area was also encircled by mixed acute and chronic inflammatory cells.

The initial inflammatory response of the body to any irritating source is acute. The events of acute inflammation are the same in all parts of the body. In response to the tissue destruction caused by the canal instrumenta-

tion, there occurs an increase in capillary permeability, resulting in an increase in tissue fluid. Changes in vascular pressure also result in a release of vascular fluids. This transference of fluids is the body's attempt to dilute the irritating substances. Margination of the polymorphonuclear leukocytes is followed by diapedesis, the emmigration of these cells out of the vascular channels. These white blood cells accumulate in the irritated area, and phagocytize cellular debris. When this phagocytic cell dies, autolysis takes place, and the intracellular vessicles containing cytolytic enzymes are released, propagating further tissue destruction. This acute inflammatory response is necessary if tissue repair is to follow. The acute phase lasts about nine days. If by this time the body's defenses have not overcome the irritating agent, then a chronic inflammatory response is elicited.

The cells characteristic of a chronic inflammatory response, macrophages, monocytes, lymphocytes, and plasma cells, were observed in the periapical tissues of the forty-two day specimens. The macrophage, like the poly, functions in the phagocytosis of any material not common to normal healthy tissue. If the inflammation persists, the monocytes enlarge, and undergo mitotic duplication. They have a similar function to that of the macrophages. It is believed that many lymphocytes seen in the area surrounding the periapical abscess have the potential of becoming macrophages, thereby increasing the number of phagocytic cells; becoming fibroblasts, which lay down the collagen fibers needed to wall off any chronic irritation; or can transform themselves into plasma cells, the primary producers of antibodies. To be sure, the chronic inflammatory response is defensive in nature.

The periapical abscesses of the forty-two day specimens indicate that

the tissue destruction within the canals was severe enough to inhibit the body's defenses from overcoming the irritation. (Fig. 2) There existed a small area where the irritant was propagating an acute inflammatory cell response. The necrotic center of the abscess of one of the giromatic prepared specimens indicates that at least in this specimen, the body was "losing the battle". If the body can reduce the irritant and proceed to a full chronic inflammatory state, then it stands a chance at "winning the war".

In comparing the one hundred eighty day specimens to the three day and forty-two day specimens, it became apparent that a more definite chronic condition existed. Except in the core of the periapical abscesses, there were few polymorphonuclear leukocytes visible. Increased capillary budding in the chronic inflammatory tissue was found in all specimens.

The results show that there was little difference between the one hundred eighty day specimens of either method of canal preparation. The pulp stump tissues had chronic inflammatory cell infiltration. The periapical tissues displayed this same infiltration of macrophages, lymphocytes and an occasional plasma cell, or they displayed a periapical abscess. In all categories, the periapical lesions in the one hundred eighty day specimens tended to have a more definite fibrous connective tissue band separating the lesion from normal appearing tissue.

An interesting observation in some of the specimens in this first one hundred eighty day category was the presence of small periradicular abscesses coronal to the periapical lesion. There was no evidence of these lateral root abscesses in any of the three day or forty-two day specimens. These periradicular abscesses occurred in specimens of both methods. (Fig. 3) Two possible explanations for this phenomena are: 1) perforation of the canal

wall during instrumentation; or 2) cytologic breakdown of the tissue elements of lateral root canals. Since lateral canals were observed in many specimens, and since no visible signs of perforation were observed in any of the specimens, the second explanation seems more plausible. The lateral canals of the three and forty-two day specimens showed some debris packed into them. Others showed normal tissue with an acute or chronic inflammatory cell infiltration. (Fig. 1) Some of the forty-two day specimens showed a few chronic inflammatory cells in the periodontal ligament adjacent to the lateral canals. It would seem that perhaps the narrowness of the lateral canals, and the small amount of tissue contained in these canals inhibited the progression of the inflammation. By forty-two days following instrumentation chronic abscesses were observed adjacent to the main canal. Since periradicular abscesses appeared coronal to the periapical abscesses, and separated from these periapical lesions, then the periradicular lesions developed between forty-two and one hundred and eighty days.

The category of teeth instrumented one millimeter short of the apex showed that after three days both methods of instrumentation had precipitated a severe acute inflammatory response in the pulp stump. It must be pointed out that in some specimens it was difficult to discern where the pulp tissue terminated and the periapical tissue began, or whether there was, in fact, any remaining pulp tissue left within the confines of the canal. It is an established fact that a continuity between the dental pulp and the periapical tissue exists. (78) It has been established that the apical foramen is not located at the anatomical apex of the root, nor does it lie flush with the outer most apical cementum. (Fig. 4) It is positioned within the confines of a convolution of the apical cementum. Depending upon the location of the

foramen from the anatomic root apex, and the accuracy of estimating its position one millimeter short of the radiographic apex, there may or may not have been pulp stump tissue left after instrumentation.

Be it pulp or periapical, this stump of tissue was indeed severely inflamed in some specimens. Although the walls of the teeth prepared conventionally were relatively free of canal debris, the stump of tissue was heavily infiltrated with polymorphonuclear leukocytes. The stump of tissue at the apical end of the giromatic prepared tooth had an equally heavy infiltration of the acute inflammatory cells. As in the teeth prepared three to four millimeters short of the apex, the canals of the giromatic prepared teeth had more tissue debris left in the canals. In the giromatic prepared teeth, where severe inflammation existed in the stump of apical tissue, a heavy infiltration of the tissue debris by polymorphonuclear leukocytes was also observed. The degree of inflammation of the periapical tissues of teeth with severely inflamed stumps differed, depending on which method of instrumentation was utilized. Dilated and engorged capillaries and resorption of the alveolar bone and cementum were common to periapical tissues of all teeth. The inflammatory cell infiltration of the periapical tissue of teeth prepared by the giromatic method showed a more moderate state of inflammation as compared to the severely inflamed periapical tissues of teeth prepared by the conventional method.

In specimens where no observable stump of apical tissue existed, there was likewise no observable signs of inflammation within the canals. Dentinal filings were located in the apical portion of these teeth. This might suggest that the filings acted as a barrier to the inflammatory cells, preventing them from contacting the tissue debris coronal to the filings. The

periapical tissues of these teeth with "inflammation-free" canals appeared relatively normal, except for some minor osteoclastic activity. No explanation for this lack of periapical inflammation could be given. Some inflammation would be expected to be in evidence three days following instrumentation, yet none was observed.

The stumps of tissue remaining within the confines of the canal forty-two days following conventional preparation one millimeter short of the radiographic apex showed some inflammation in two specimens, and in a third specimen the tissue appeared normal. Dentinal filings packed at the apical end of the canal of this third specimen appeared to be separated from normal tissue by collagen fibers. The periapical tissues of this third specimen likewise appeared relatively normal. There were a few chronic inflammatory cells present in the bone marrow spaces, and a very small localization of polys near the foramen.

In the canals whose stumps were inflamed, the residual tissue debris showed a mild infiltration of polys. Dentin and cementum resorption was evident. The periapical tissues of these specimens displayed marked severe inflammation. The periapical abscesses were much larger in depth than the abscesses of the forty-two day specimens prepared three to four millimeters short of the apex. Dentin filings were observable in the area of acute inflammatory cells. Multinucleated giant cells were positioned just peripheral to the acute inflammatory cells. Among the chronic inflammatory cells, bands of epithelial cells with mitotic figures were visible. In this particular monkey, foam cells and a rare plasma cell with Russell bodies were noted in the vicinity of the epithelial cells.

The giromatic prepared specimens in this forty-two day, one millimeter short category also had inflammation in the canals. Again there was far more tissue debris left in the canals. This residual tissue debris and the tissue in a lateral canal, both showed infiltration of polymorphonuclear leukocytes. (Fig. 1) Polys were highly concentrated in the stump tissue adjacent to canal debris. Some scattered chronic inflammatory cells were observed in the stump tissue of one specimen. Although a moderate amount of chronic inflammatory cells were present some distance beyond the apex of this specimen, most of the periapical tissue was obliterated by poor histologic preparation. The other specimen showed relatively normal appearing periapical tissue, moderately infiltrated by polys where the periapical tissue entered the apical foramen. As was mentioned, the apical stump of tissue for this specimen was inflamed. It might have been expected that the periapical tissue of this tooth should have had an abscess, as with the conventionally prepared teeth with inflamed stumps in this category. One explanation for the milder state of inflammation may be that the giromatic method destroyed less tissue than the conventional filing method. Perhaps another explanation is related to the root canal morphology. The specimen being discussed, one of the giromatic teeth prepared one millimeter short of the radiographic apex, and showing a relatively normal periapical tissue after forty-two days, had two small canals that merged apically to form one canal. Instrumentation was terminated, as interpreted on the histologic specimens, at the junction where these canals merged. If the apical stump of tissue had sufficient vascular drainage, and since the instrumentation was limited to the individual canals, perhaps the body's defenses overcame the irritation at the acute stage. Perhaps the tissue is completing a healing phase, showing only a few inflammatory

cells. It may be that the tissue is only now beginning to break down, and exists in a transitional inflammatory stage between a healthy state and a severely inflamed state.

There is another possible explanation for the results of this forty-two day, one millimeter short category. As mentioned above, the ideal location for terminating intracanal preparation is at the cementodentinal junction, found approximately one millimeter short of the anatomical root apex, where the pulpal and periapical tissues merge. It was also mentioned that the operator must rely on radiographic interpretation of this one millimeter short location. The results of this study show that the periapical tissues of both giromatic prepared specimens and one conventionally prepared specimen in this category were in a relatively normal state. If the instrumentation of these specimens did, in fact, terminate at the ideal apical location, the cementodentinal junction, perhaps a relatively normal state of health is the expected result. The narrowest portion of the canal and the least possible amount of tissue exposed directly to the irritation are located here. If radiographic interpretation of the remaining two conventionally prepared teeth was incorrect, or the location of the cementodentinal junction was located at a distance greater than one millimeter from the apex, then these teeth may have, in fact, been instrumented beyond the apex. The severe inflammatory condition of these two specimens is comparable to the severe inflammation of specimens of the last category, instrumentation beyond the apex, for the same forty-two day period.

Based on the quantity and concentration of inflammatory cells, and the size of the existing pathologic lesions, specimens instrumented one millimeter short of the radiographic apex by the giromatic method tended to appear

more severe in comparison to the conventionally prepared specimens when observed one hundred eight days following instrumentation. (Fig. 4 and 5)

When intracanal preparation was extended beyond the radiographic apex, there was no observable stump of apical tissue. One conventionally prepared specimen showed no sign of inflammation in the canal three days following instrumentation. The walls of the canal were free of residual tissue. However, the remaining conventionally prepared specimen and both of the giromatic prepared specimens displayed acute inflammation. The canals prepared by the giromatic method were found to contain greater amounts of residual tissue and debris, and therefore, as might be expected, the inflammation was more severe.

When the irritating agents, the endodontic files came in direct contact with the periodontal tissues, the inflammation was generally more severe than in the periapical tissues of any of three day specimens instrumented short of the apex. Polymorphonuclear leukocytes were highly concentrated in the alveolar marrow spaces. Although the preparation extension beyond the apex appeared to be equal when comparing specimens of both methods, the depth of polymorphonuclear leukocyte infiltration into the alveolar bone appeared to be greater adjacent to teeth prepared by the giromatic method.

One specimen prepared conventionally displayed normal periodontal tissues. The instrumentation of this three day specimen had apparently not extended beyond the apex, as was intended. Certainly direct contact with the irritating agents, the files, would have elicited visible signs of inflammatory changes by three days.

Forty-two days after instrumentation of teeth in this beyond the apex

category, the conventionally prepared teeth showed some residual tissue debris and dentin filings, but only one specimen showed any sign of inflammation, that being the resorption of dentin near the apical foramen. The canals of teeth prepared by the giromatic method showed a greater amount of residual tissue, and an infiltration by polymorphonuclear leukocytes in that tissue.

One conventionally prepared specimen displayed a moderate amount of inflammation in the form of a periapical abscess. The remainder of specimens in this category, for both convention and giromatic methods, all displayed severe inflammation in the periapical tissues. (Fig. 6) Large periapical abscesses, with necrosis in two giromatic prepared specimens, were observed. Bands of proliferating epithelial cells with mitotic figures could be seen within the polymorphonuclear leukocyte core of the abscesses. Plasma cells with Russell bodies and foam cells were located among the other cells characteristic of chronic inflammation, the macrophages, lymphocytes and plasma cells. No eosinophils were observed in any section studied. Noticeably more advanced alveolar bone and cementum resorption were present compared to the previously discussed categories. These findings confirmed the belief that the amount of inflammation produced in response to the irritation is proportional to the amount of irritating agent present. When instrumentation was confined to the canals, the periapical response was generally much milder than when the irritation was applied directly to the periapical tissues. In the first two categories, where the instrumentation was confined to the canals, the periapical inflammation developed secondary to intracanal inflammation. In the instrumentation beyond the apex category, the periapical response was not the result of the spread of inflammation from the canal but

the result of direct contact with the irritating agents.

One hundred eighty days following instrumentation beyond the apex, the specimens of both methods of canal preparations showed similar results. An exception to this similarity of results was found in one of the conventionally prepared canals. This canal had granulomatous tissue at its apical end, and hemorrhagic cells filled the remainder of the canal. The exact cause of this hemorrhage in the canal is impossible to determine from the histologic sections studied. Granulomatous tissue, like that found in the apical portion of this canal, is vascular by its very nature. Why this tissue should hemorrhage after such a long period following instrumentation escapes explanation. It is possible that the root was fractured during canal preparation, or by mastication of food by the animal after canal preparation. Hemorrhage into the canal is a frequent finding in cases of fractured roots following removal of the pulp. Since there was no apparent clotting of the erythrocytes, the root fracture would have to have occurred shortly prior to sacrifice of the animal. During resection of the jaws, following sacrifice, the occlusal seal of the tooth could have been broken, and some of the unclotted erythrocytes could have seeped into the canal. This is another possible explanation for the presence of hemorrhage in the canal.

Most periapical specimens for the one hundred eighty day period following instrumentation beyond the apex displayed severely inflamed tissues. The size of the lesions were generally much larger than those of any other category of the study. The two most severely inflamed specimens of the study were found in this category. Both of these specimens had been prepared by the giromatic system. The amount of hard tissue resorption was quite extensive in these two specimens.

The exact mechanism of resorption, be it bone, cementum, or dentin, is not fully understood. It is believed that undifferentiated mesenchymal cells are transformed into macrophages. These cells coalesce to form multinucleated giant cells called osteoclasts, cementoclasts or dentinoclasts, depending upon the type of tissue being resorbed. Histologically these clastic cells are observed in Howship's lacunae, a scalloped area of the hard tissue being resorbed. According to Seltzer, in a study by Hancox and Boothroyd, clastic cells were found to have brushed borders which sweep over the surface being resorbed. Fulmer and Lazarus postulated that collagenase was the enzyme responsible for the depolarization of ground substance leading to the resorption of calcified tissue. (78)

One hundred and eighty days following instrumentation, some degree of inflammation was evident in almost all specimens. As noted by Seltzer, certain factors could have been responsible for this inflammatory persistence. (78)

1. The occlusal amalgam seal of the teeth could have weakened, and allowed seepage of oral fluids into the unfilled portions of the root canal, thereby contaminating the canal.
2. The necrosis of residual tissue debris and the apical stump tissue could have served as a chronic source of irritation, causing any existing inflammation to persist.
3. The irritating agents can initiate a tissue response of one type for one individual, and different from the response of another individual. Seltzer calls this "biologic variations in tissue responses."

A notable example of this "biologic variation" was the presence of

large numbers of plasma cells with Russell bodies in the periapical tissues of specimens of one animal in the study. As mentioned earlier, plasma cells are the principle producers of antibodies. It is believed that the Russell bodies in this form of plasma cell contain immunoglobulins, and that upon degeneration of the cell, these inclusions are released into the inflamed area. An anachoretic effect stemming from any systemic infection in this monkey could have stimulated the production of these cells and their migration to the inflamed periapical tissues, or it could be that the production of large numbers of plasma cells with Russell bodies was characteristic of the "biologic variation" of this individual monkey.

SUMMARY

While following established endodontic procedures, the root canals of three rhesus Macaca mulatta monkeys were instrumented by either the conventional hand manipulated or the giromatic mechanically manipulated method. The canals were prepared three to four millimeters short of the radiographic apex, one millimeter short of the radiographic apex, or beyond the radiographic apex. The animals were sacrificed three days, forty-two days, and one hundred eighty days following the instrumentation. Block sections were taken following sacrifice, and histologic sections were prepared using hematoxylin and eosin, and Mallory's aniline blue stains. The sections were studied, and observations recorded. Comparative histopathologic evaluation of pulp stump and periapical tissues were made between specimens instrumented by the two methods, corresponding to their respective three day, forty-two day, or one hundred eighty day periods.

The results showed that:

1. More residual cellular debris remained in all portions of the canals when the giromatic method of instrumentation was used.
2. The canal walls were more irregular and less smooth when the giromatic method of instrumentation was used.
3. There was more predentin left along the canal walls and more untouched pulpal tissue left along the canal walls when the giromatic method of instrumentation was used.
4. Slightly more inflammation was present in the pulp stump and periapical tissues of specimens instrumented by the giromatic

method, as compared to the conventional filing method.

It should be noted, that although the giromatic method tended to produce slightly more inflammation than the conventional method in almost every category, the sample size was too small to allow a statistical analysis. Therefore, based on the results of this study, it might be concluded that both the conventional and giromatic methods of root canal instrumentation caused inflammation of relatively equal degrees of severity.

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APPENDIX

Abbreviations for Tables

MI	=	Mild Inflammation
MAI	=	Mild Acute Inflammation
MCI	=	Mild Chronic Inflammation
Mod I	=	Moderate Inflammation
SI	=	Severe Inflammation
SAI	=	Severe Acute Inflammation
VSI	=	Very Severe Inflammation
ESI	=	Extremely Severe Inflammation
PA	=	Periapical Abscess
PMN	=	Polymorphonuclear Leukocyte
CIC	=	Chronic Inflammatory Cells (Lymphocytes, Plasma Cells, and Macrophages)
ABR	=	Alveolar Bone Resorption
CR	=	Cementum Resorption
DR	=	Dentin Resorption
PDL	=	Periodontal Ligament
NI	=	No Visible Sign of Inflammation
NAT	=	Normal Appearing Tissue
ALHP	=	Area Lost in Histologic Preparation

Table 1

Three Day

		Conventional 3 to 4mm Short	Giromatic 3 to 4mm Short
Root Canal Contents	A	MAI. Few PMN in coronal part of pulp stump tissue; remainder of pulp stump NAT; little tissue debris in coronal one third; packed debris and dentin filings in apical one third.	A MAI. PMN infiltration of pulp stump tissue; lateral canal with mild PMN infiltration.
	B	MAI. Few PMN in pulp stump; torn fibrous tissue coronally along walls; cleaner walls apically; loosely arranged tissue debris and dentin filings toward apical end of canal preparation.	B MAI. PMN infiltration of pulp stump tissue; tissue in coronal third packed in swirled appearance; dentin filings packed in middle third.
Periapical Tissues	A	NAT. Increased vascularity	A MAI. Few PMN adjacent to apical foramen; two PMN adjacent to lateral canal foramen.
	B	NAT	B ALHP

Table 2

Forty-two Day

		Conventional 3 to 4mm Short	Giromatic 3 to 4mm Short	
Root Canal Contents	A	MAI. PMN infiltration of pulp stump tissue; dentin filings adjacent to apical tissue.	A	SAI. PMN fill apical portion of canal; dental filings adjacent to apical tissue.
	B	ALHP	B	ALHP
Periapical Tissues	A	Mod I. Small PA; Core of PMN surrounded by CIC.	A	Mod I. Small PA with Necrosis. Necrotic center in core of PMN surrounded by CIC; Calcified debris in area of necrosis.
	B	ALHP	B	SI. Large PA; CIC packed in alveolar marrow spaces several millimeters from apex.

Table 3

One Hundred Eighty Day

Conventional 3 to 4mm Short		Giromatic 3 to 4mm Short		
Root Canal Contents	A	NI; Dentin filings packed toward apical end. Apical stump ALHP; canal walls clean.	A	NI; Some dentin filings.
	B	Same as A.	B	Same as A.
	C	MCI; CIC infiltration of pulp stump tissue debris.	C	ALHP
	D	Same as C.	D	MI; CIC infiltration of pulp stump tissue and debris.
	E	MCI. Few CIC scattered in debris; dentin packed at apex; canal walls clean.	E	Same as D.
	F	Same as E.	F	Same as D. Large quantity of debris apically.
Periapical Tissues	A	NAT. Slightly widened PDL space.	A	Relatively normal. Several dilated vessels in widened PDL space.
	B	Same as A.	B	Mod I. Many CIC scattered through loosely arranged connective tissue fibers; foam cells; dense connective tissue fibers wall off lesion.
	C	Mod I. PA; Lesion extends coronally along sides of root.	C	Mod I. Small, localized PA; capillary budding peripheral to core of abscess.
	D	MI. Few CIC with capillary budding; small abscess in PDL at middle root level.	D	MI. Small PA; Chronic granulomatous tissue.
	E	Same as A.	E	ALHP
	F	Relatively normal. Very few CIC scattered in slightly widened PDL space.	F	Mod I. Heavy CIC infiltration; widened PDL space.

Table 4

Three Day

		Conventional 1mm Short	Giromatic 1mm Short
Pulp Canal Contents	A	SAI. PMN packed in apical stump tissue; very little debris.	A SAI. Middle and apical thirds with one clean wall and opposite wall with predentin and debris infiltrated by high concentration of PMN; PMN concentrated in apical stump tissue.
	B	NI. Coronal one third with predentin on walls; middle one third with clean walls; apical third with dentin filings and some tissue debris along one wall.	B NI. Coronal and middle thirds with predentin and debris along one wall; other wall clean; dentin filings in apical end of preparation.
Periapical Tissue	A	SAI. High concentration of PMN; edema; dilated capillaries; little ABR.	A Mod I. PMN in masses and scattered in widened PDL space; dentin filings in PMN concentrated areas; some ABR and CR.
	B	Relatively normal; little ABR.	B Relatively normal. Some ABR.

Table 5

Forty-two Day

		Conventional 1mm Short	Giromatic 1mm Short
Root Canal Contents	A	MI. PMN infiltration of debris; DR; CR.	A Mod I. PMN concentrated with CIC in apical third; PMN on border of debris in lateral root canal; debris in all thirds of canal.
	B	NAT. Connective tissue fibers separate dentin filings from normal stump tissue.	B MI. PMN infiltration of tissue at junction of two canals; canals merge to form one canal apically..
Periapical Tissues	A	SI. PA; High concentration of PMN and dentin filings in core of PA; CIC around PMN core; Multinucleated giant cells; epithelial cell proliferation in PA; foam cells; plasma cells with Russell bodies; ABR.	A Relatively normal; widened PDL.
	B	Relatively normal; few CIC in marrow spaces; small mass of PMN; little ABR.	B MI. PMN infiltration of tissue as it enters apical foramen.
	C	SI. PA; PMN and CIC in alveolar marrow spaces; ABR; CR.	

Table 6

One Hundred Eighty Day

Conventional 1mm Short		Giromatic 1mm Short		
Root Canal Contents	A	NAT. Dentin filings packed at apex.	A	Stump tissue ALHP; some debris in canal.
	B	MI. Few CIC scattered in stump tissue; dentin filings packed; canal clean.	B	MI. Scattered CIC in amorphous debris; dentin packed near apex; granulomatous tissue extend into canal from PDL.
	C	MI. CIC at apical end; dentin filings packed coronal to CIC canal clean.	C	Mod I. Heavy concentration of CIC and PMN in debris.
	D	MI. CIC and PMN in apical portion of canal.	D	Stump tissue ALHP. Canal clean.
	E	Mod I. High concentration of CIC in debris.	E	MI. CIC in stump tissue.
	F	NI. Dentin filings packed apically; some debris in canal.	F	Same as A.
	G	Same as F.	G	Same as A.
Periapical Tissues	A	Mod I. Small granuloma, ABR, CR; dense collagen fibers capsule.	H	Same as A.
	B	MI. Scattered CIC in loosely arranged fibers, dense collagen fiber capsule.	I	MI. CIC in apical debris.
	C	Same as B.	A	ALHP.
	D	Mod I. Small PA.	B	ALHP. Scattered CIC in PDL.
	E	SI. Large PA; much ABR.	C	SI. Large PA; lesion extend coronally along sides of root.
	F	NAT.	D	NAT. Slightly wide PDL.
	G	NAT.	E	Mod I. Small PA with collagen fiber capsule; ABR.
		F	VSI. Large PA with necrosis extending coronally almost to furcation.	
		G	NAT.	
		H	Mod I. Small PA	
		I	SI. Large PA with collagen fiber capsule CIC cells.	

Table 7

Three Day

		Conventional Beyond			Giromatic Beyond
Root Canal Contents	A	PMN in debris along walls; debris increasing in concentration from middle to apical one third; hemorrhage; lateral canal containing NAT.		A	PMN infiltration of debris packet at apical end; tissue debris containing odontoblasts throughout canal; sections of odontoblasts and predentin remain intact along walls.
	B	NI. Dentin filings in canal; walls appear smooth.		B	SAI. High concentration of PMN in apical one third; predentin left on walls in coronal one third; dentin filings in middle one third.
Periapical Tissues	A	NAT		A	SAI; diffuse lateral extension of PMN; high concentration of PMN in alveolar marrow spaces; hemorrhage.
	B	Mod I. Mild PMN infiltration of PDL; Some PMN in alveolar marrow spaces; edema; widened PDL.		B	Same as A.

Table 8

Forty-two Day

		Conventional Beyond	Giromatic Beyond
Root Canal Contents	A	NI. Tissue debris and dentin filings in canal.	A MOD I. PMN in filtrate debris at apical foramen; DR and CR extensive near apical foramen.
	B	DR. Near apical foramen; disorganized tissue debris.	B MOD I. PMN infiltration of debris. C ALHP.
Periapical Tissue	A	SI. PA; plasma cells with Russell bodies; ABR; epithelial cell proliferation in CIC area of PA.	A SI. PA with Necrosis; epithelial cell proliferation, multinucleated giant cells; plasma cells with Russell bodies and foam cells in CIC area of PA; severe ABR; alveolar marrow spaces filled with CIC.
	B	MOD I. PA.	B Same as A. C VSI. PA; epithelial cell proliferation in CIC area of PA; ABR; CIC packed in alveolar marrow spaces.

Table 9

One Hundred Eighty Day

		Conventional Beyond			Giromatic Beyond
Root Canal Contents	A	Extravasated erythrocytes in much of canal; granulomatous tissue apical to erythrocytes; apical foramen ALHP.		A	Relatively clean canals; some dentin filings.
	B	CIC. infiltration of debris.		B	CIC. infiltration of debris.
	C	Same as B.		C	Same as B.
	D	Relatively clean canal.		D	Same as B.
	E	Same as D.		E	Same as A.
Periapical Tissues	A	NAT.		A	Most of section ALHP; Heavy CIC concentration adjacent to apex.
	B	Most of section ALHP; Heavy CIC concentration adjacent to apex.		B	VSI; large PA.
	C	Mod I. Granulation tissue appears to border path of instrument into alveolar bone.		C	ESI. Deep and extensive PA; extensive ABR and CR.
	D	VSI; large PA.		D	Same as B.
	E	Same as D.		E	Same as B.

Fig. 1 Giromatic instrumentation 1mm short of the radiographic apex, 42 days post-operative. Dentin filings (df) beyond termination of canal preparation; inflammatory cells (arrows) apical to dentin filings; tissue debris (td) in root canal; lateral canal (LC); normal apical stump tissue (NST); apex (A). X40.

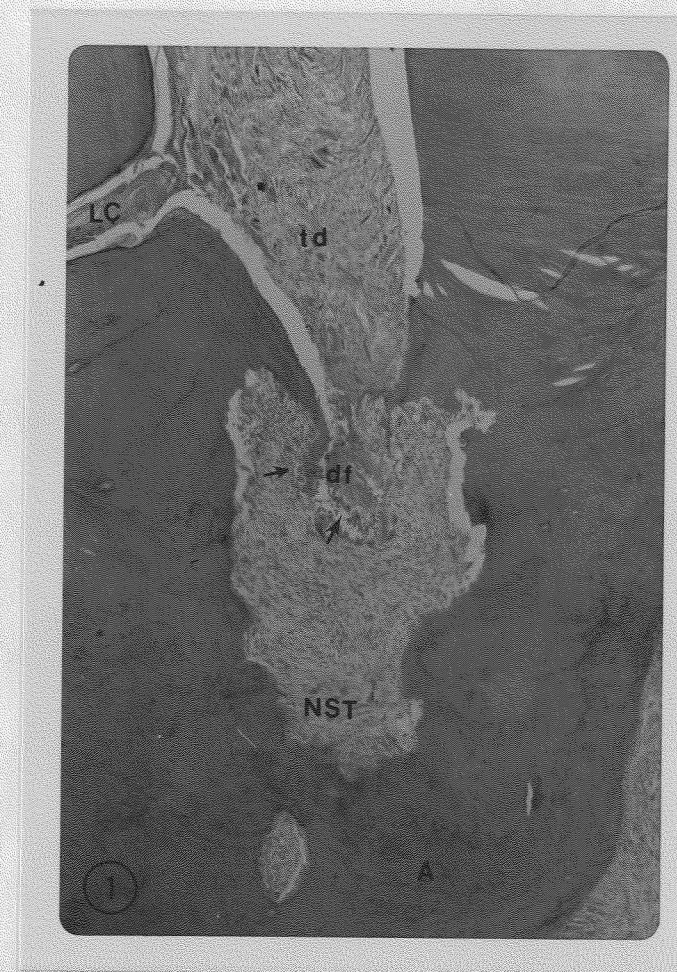


Fig. 2 Giromatic instrumentation 3 to 4mm short of the radiographic apex, 180 days post-operative. Tissue debris (td) in root canal; large periapical abscess (PA); root apex (A) X25.



Fig. 3 Conventional instrumentation 3 to 4mm short of the radiographic apex, 180 days post-operative (apical stump tissue not shown). Periapical abscess (PA) separated from lateral canal abscess (periradicular abscess) (LA) by fibrous connective tissue band (fb); fibrous connective tissue band encircles lesions (arrows); root apex (A); root canal (RC) X25.

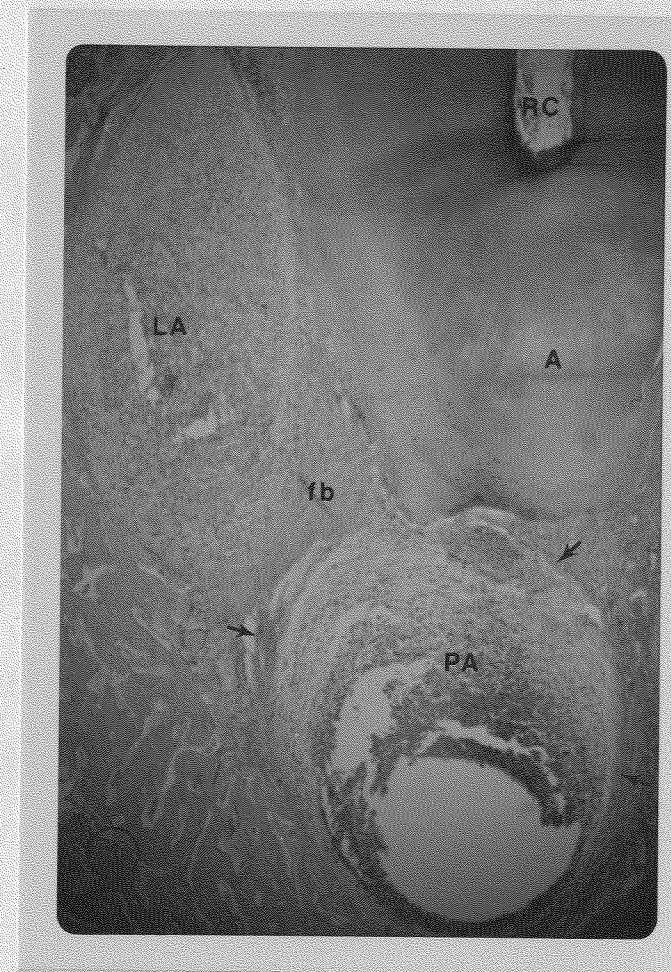


Fig. 4 Conventional instrumentation 1mm short of the radiographic apex, 180 days post-operative. Normal periapical tissue (NPT) beyond termination of canal preparation (arrows); packed dentin filings (df). apical foramen located coronal to anatomical root apex. X25



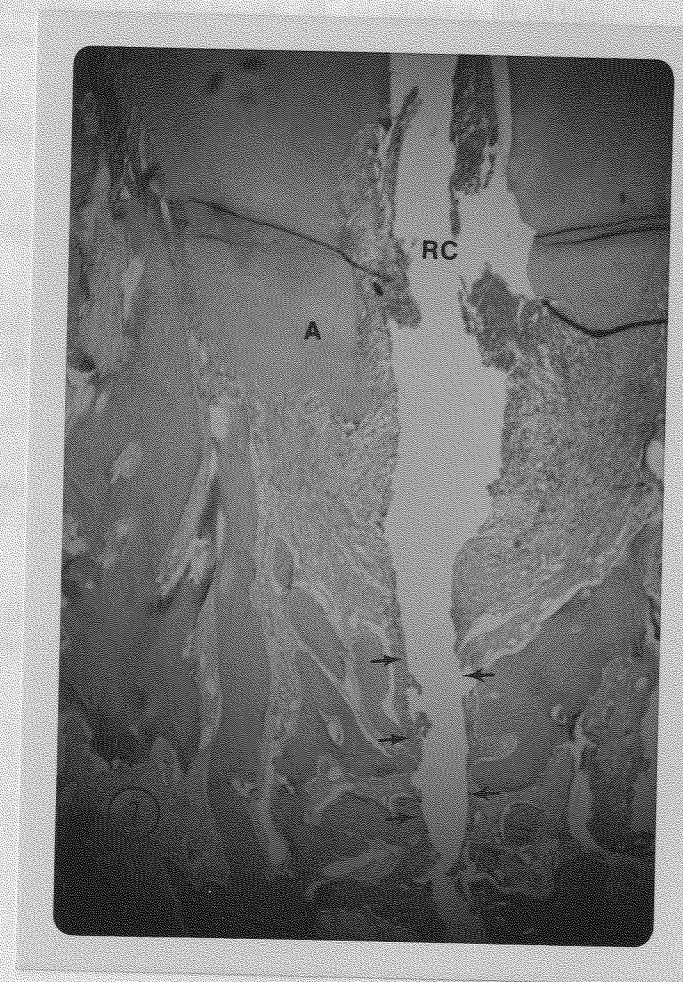
Fig. 5 Giromatic instrumentation 1mm short of radiographic apex, 180 days post-operative. Large periapical abscess (PA) extending coronally adjacent to root; root resorption (arrows) adjacent to abscess; root apex (A); root canal (RC) X25.



Fig. 6 Giromatic instrumentation beyond the radiographic apex, 42 days post-operative. Tissue debris (TD) in root canal, large periapical abscess (PA); root apex (A) X25.



Fig. 7 Conventional instrumentation beyond the apex, 180 days post-operative. Outline of instrumentation (arrows) visible in alveolar bone; periapical inflammation localized to area adjacent to path of instrumentation; root canal (RC); root apex (A) X25.



APPROVAL SHEET

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The thesis/dissertation is therefore accepted in partial fulfillment of the requirements for the degree of Master of Science.

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